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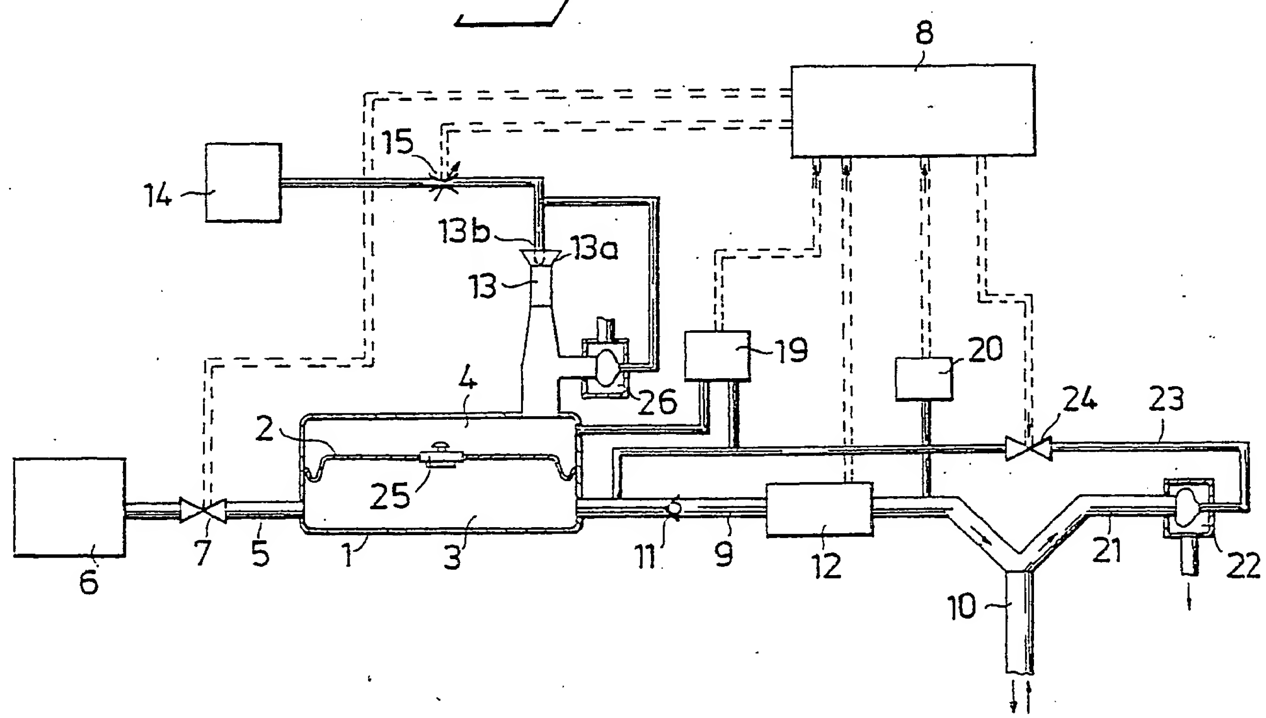
(54) A lung ventilator

(57) The invention relates to a lung ventilator which includes a breathing-gas chamber or breathing-gas bag (3) having flexible walls and a variable volume which is enclosed in a rigid driving-gas chamber (4). The breathing-gas chamber is connected to a source (6) of breathing gas, and receives and collects the gas and then supplies it to the airways of a patient through an inspiration line (9) and a hose (10). A driving-gas chamber (4) is connected to an arrangement (13-15) for supplying air to the driving-gas chamber (4) so that the breathing gas chamber is compressed and breathing-gas is fed through the inspiration line and the hose to the airways of the patient in the form of a breath. The infeed or air into the driving-gas chamber (4) is controlled by a central control unit (8) which generates a control signal for an electrically controlled regulating means (15) which is arranged to control the infeed of air into the driving-gas chamber (4), and thus the pressure created therein and in the airways of the patient, in response to the applied control signal.

Fig. 1



SPECIFICATION

A lung ventilator

THE PRESENT INVENTION relates to lung ventilators and especially to lung ventilators of the kind comprising a breathing-gas chamber having at least partially flexible walls and a variable volume and which is enclosed in a driving-gas chamber having rigid walls, whereat the breathing-gas chamber is connected, through a supply line, with a breathing-gas source for receiving and collecting breathing gas while increasing in volume, and can be connected to the airways of a patient through an inspiration line, while the driving gas chamber is connected with a means for feeding air thereinto so as to compress the breathing-gas chamber, to drive breathing gas collected therein to the patient through said inspiration-line, said line incorporating a check valve which permits gas to flow only in the direction towards the patient, there being provided an expiration line which can be connected to the airways of the patient and which incorporates an expiration valve which is openable only during the expiration phase of the breathing cycle of the patient and which permits gas to flow only in a direction from said patient.

Various, different embodiments of lung ventilators of this kind are previously known to the art. Examples of known lung ventilators of the kind mentioned include the respiratory systems ER300 and ECS2000, sold by Engstrom Medical AB, and the respiratory system described in Swedish Patent Specification 388,127.

A common problem with all such lung ventilators is the very large number of different modes of respiratory treatment which doctors of today want available, and also the desire to be able to vary the different treatment parameters within wide limits. Thus, it may be desired, for example, to be able to subject the patient to controlled mechanical ventilation (CMV), i.e. a continuous, forced or mechanical ventilation of the patient, with a variable inspiration frequency, a variable relationship between the duration of the inspiration phase and the expiration phase, variable tidal volume and, if possible, a variable pressure-curve of the pressure in the respiratory ducts (hereinafter referred to as airways) of the patient during the inspiration phase. It may also be desired to subject the patient to CMV treatment with a variable positive end expiratory pressure (PEEP), i.e. the pressure in the airways or lungs of the patient at the end of the expiration phase is maintained at a level higher than atmospheric pressure instead of returning to zero. Another form of respiratory treatment which doctors would have available is the intermittent, mandatory ventilation process (IMV) in which the patient breathes an accurately predetermined and controlled amount of breathing gas spontaneously through the lung ventilator, but occasionally has forced upon him a mandatory breath of a given, adjustable tidal volume, at a given predetermined and adjustable frequency (hereinafter referred to as a mandatory breath). It is often desired to subject a patient to the IMV-process with continuous positive airway pressure (CPAP) while breathing spontaneously, i.e. with a predetermined and adjustable continuous airway overpressure, in order to facilitate spontaneous respiration at this pressure level. It is also desirable in this kind of respiratory process that the pressure pattern and flow pattern in the airways of the patient has a given, predetermined profile during each mandatory breath. In addition, it is naturally desirable to have full control over the volume of gas obtained by the patient during spontaneous breathing. Another kind of respiratory treatment is the intermittent demand ventilation (IDV), in which the patient has forced upon him a mandatory breath of predetermined, adjustable tidal volume and a predetermined adjustable pressure-flow-profile each time the patient himself attempts to take a breath, i.e. the patient himself initiates the mandatory breath and establishes the frequency of breathing. It is often desirable even with this kind of respiratory process for breathing to take place at a predetermined, continuous positive airway pressure (CPAP).

It is desirable that all of the aforementioned, differing respiratory treatment processes, and also other, not previously mentioned treatment modes with their different, variable parameters, can be effected with the use of one and the same lung ventilator, or at least with lung ventilators whose essential components are constructed in one and the same manner, but which during manufacture are supplemented or modified with differing auxiliary components and control functions, as that they are suited for different types of respiratory treatment processes. This would simplify the overall manufacture of such lung ventilators and render them less expensive, besides reducing purchasing costs. Further, the lung ventilator equipment would be easier to handle and to maintain in hospital, since all of the equipment would be at least of the same basic design.

It is also desirable that a lung ventilator is of the simplest possible mechanical design, since this would greatly simplify the manufacture thereof, thereby rendering it less expensive, and would further increase the operational reliability and efficiency of the lung ventilator. It would also be to great advantage if the lung ventilator were so constructed that the different desired operational forms and variation possibilities with regard to the different parameters could be achieved by corresponding construction or programming of a central electronic control unit, since such a control unit can be produced, with present day technology, relatively cheaply and with a high degree of reliability. Such a control unit can also be relatively easily modified or reprogrammed for the different desired operational forms of the lung ventilator, at moderate costs. Such an electronic control unit requires but a small space and is relatively light, which is an advantage when considering that present day lung ventilators should be as small and as light as possible, since it is often necessary to be able to move said ventilators between different locations.

Consequently, the object of the present invention is to provide a lung ventilator which fulfils the

aforementioned requirements and desiderata.

Accordingly, one aspect of the invention provides a lung ventilator comprising a variable volume breathing gas-chamber which, in use, responds to the pressure in a driving gas-chamber to supply air to a patient, a control unit which generates a control signal having a predetermined shape during each breath, and an electrically controllable regulating means which is responsive to the control signal to vary the pressure in the driving-gas chamber.

In a preferred embodiment another aspect of the invention provides a lung vnetilator comprising an inspiration line which incorporates a check valve which permits gas to flow only in a divider towards a patient, an expiration line which incorporates an expiration valve, which is operable only during the expiration phase of a breathing cycle of the patient, a variable volume breathing-gas-chamber which is connected through a supply line to a breathing gas source and through the inspiration line to the airways of the patient, a driving-gas chamber which is connected to an air supply arrangement so that upon supply of air to the driving gas chamber the breathing gas chamber is compressed to drive breathing gas into the patient, the air supply arrangement comprising an electrically controllable regulating means arranged to vary the effective air infeed and therewith the pressure generated in the driving gas chamber in dependence on an applied control unit which generates a control signal having a predetermined shape during each breath and sends this signal to the regulating means.

By providing the means for feeding air in the driving-gas chamber of a lung ventilator according to the invention with an electrically controllable regulator means which is able to vary the effective air-input to the driving-gas chamber, and therewith the pressure generated therein, in dependence on an applied electric control signal, the possibility is obtained of determining varying, controlling and/or regulating the pressure prevailing in the driving gas chamber, and therewith also in the breathing-gas chamber, as desired, during different phases of a respiratory treatment process, which provides a high degree of flexibility with regard to the kind of respiratory treatment applied and the course which such treatment takes.

It has been found that such a controllable or regulatable air-input to the driving-gas chamber can be obtained in a relatively simple manner, when said air input arrangement comprises an ejector which is coupled between the driving-gas chamber and surrounding atmosphere and has a driving nozzle connected to a compressed-air source through an electrically controllable flow regulating valve forming said regulating means, or when said arrangement comprises a fan arranged between the surrounding atmosphere and the chamber, and an outlet from said chamber to said surrounding atmosphere, said outlet including an electrically controllable, variable throttle arrangement which forms said regulating means. The latter arrangement has the important advantage that no source of air under pressure is required, and hence a lung ventilator having this construction can also be used in places where there is no pressurized-air network or where the air delivered by an existing air network is not of a quality with respect to purity and dryness, such that a lung ventilator can or ought to be connected to the network.

Exemplary embodiments of the invention will now be described with reference to the accompanying schematic drawing, in which:

Fig. 1 illustrates schematically, and by way of example, the principle construction of a lung ventilator designed in accordance with the invention; and having one embodiment of an arrangement for feeding air into the driving-gas chamber and controlling the pressure therein; and

Fig. 2 is a partial view of a lung ventilator according to the invention provided with another arrangement for feeding air into the driving-gas chamber and controlling the pressure therein.

The lung ventilator illustrated in Fig. 1 includes, in a manner known per se, a rigid container 1 which is divided into a breathing-gas chamber 3 and a driving-gas chamber 4 by means of a flexible diaphragm or membrane 2 which is movable between the two mutually opposite major walls of the container. The breathing-gas chamber is connected to a source 6 of breathing gas via a supply line 5. The source 6 is only shown schematically and may be of any suitable construction. The breathing-gas source 6 is arranged to deliver breathing gas of desired composition and of other desired properties, such as temperature and humidity.

The breathing-gas source is suitably designed to deliver a constant flow of breathing gas which can be preset to a desired value. The supply line 5 may incorporate a closure valve 7, which is held open or closed in a controlled manner from a central control unit 8. The breathing-gas chamber 3 is also connected, through an inspiration line 9, to a hose 10 for communication with the airways of the patient, in a suitable manner known per se. The inspiration line 9 incorporates in a conventional manner a check valve 11 which will only permit gas to flow in a direction towards the patient, and may also incorporated a flow meter 12 which senses the flow of breathing gas passing through the line 9 to the patient and sends a corresponding measuring signal to the control unit 8. The flow meter 12 may be of any suitable design and, to advantage, comprises a throttle means arranged in the line 9 and a differential-pressure transducer which detects the drop in pressure across the throttle means, said pressure drop being proportional to the gas flow, as is well known.

The driving-gas chamber is connected to an air-infeed arrangement for feeding air into the chamber, so as to increase the volume of said chamber and/or to generate a desired pressure therein, in a manner to cause the breathing-gas chamber to be compressed and the breathing-gas collected therein to be driven out through the inspiration line 9, to the hose 10 and therewith to the airways of the patient, and also in a manner such that a desired pressure corresponding to the pressure in the driving-gas chamber 4 is obtained in the breathing-gas chamber 3. In the embodiment of the invention illustrated in Fig. 1, the air-infeed arrangement comprises an ejec-

tor 13 having an ejector tube 13a which communicates with the surrounding atmosphere, and a driving nozzle 13b which is connected to a compressed-air source 14 via an electrically controllable flow-regulating valve 15 having a constriction or throttle means which can be varied between a fully closed position and a fully open position in dependence on the magnitude of the applied electric control signal, so that the drive flow through the nozzle 13b of the ejector can be varied. The pressurized-air source 14, which is only shown schematically, normally comprises a fixed air network present on the site in which the lung ventilator is used, said network being connected to the control valve 15 via requisite pressure-regulating and filtering devices. The regulating valve 15 is controlled from the central control unit 8. the flow of air under pressure from the drive nozzle 13b of the ejector, which flow can be varied by means of the valve 15, entrains therewith air from the surrounding atmosphere through the ejector tube 13a, thereby amplifying the flow and whereby a greater flow of air is fed into the driving-gas chamber 4, so that said chamber can be expanded and the breathing-gas chamber 3 compressed thereby to a corresponding degree, causing breathing-gas to be driven through the line 2 to the airways of the patient connected to the ventilator. It will be understood that the pressure in the breathing-gas chamber 3 coincides with the pressure prevailing in the driving-gas chamber 4, since the flexible diaphragm 2 is substantially freely movable without any force development. The resulting flow from the ejector 13 into the driving-gas chamber 4 depends upon two factors; namely the flow from the driving nozzle 13b, which flow is determined by the setting of the regulating valve 15, and by the prevailing counter pressure in the driving-gas chamber 4. The higher the pressure in the driving-gas chamber 4, the lower the total flow from the ejector 13 for a given flow from the driving nozzle 13b, i.e. a given control signal to the regulating valve 15. When a certain pressure prevails in the chamber 4, the so-called ejector stagnation pressure, there is no resultant flow from the ejector 13 into the chamber 4; the whole of the kinetic energy in the flow of pressured air from the ejector nozzle 13b is consumed in the generation and maintenance of the stagnation pressure in the chamber 4. The greater the flow of compressed air from the driving nozzle 13b of the ejector, i.e. the wider the regulating valve 15 is open, the greater the stagnation pressure. This characteristic of the ejector arrangement is utilized, for generating desired pressure and flow profiles of the breathing gas supplied to the patient. When the regulating valve 15 is fully closed and the flow of compressed air to the driving nozzle 13b of the ejector thus interrupted, the chamber 4 is vented to the surrounding atmosphere through the ejector tube 13a, so that the pressure in the chamber 4 equals atmospheric pressure. In certain conditions, the venting capacity through the ejector tube 13a may be too low, however, and hence an additional venting valve 36 may be provided. This venting valve is held closed by the feed pressure to the driving nozzle 13b of the ejector, and hence said valve is automatically opened when the regulating valve 15 is closed and the ejector stopped.

Fig. 2 illustrates a further possible and advantageous embodiment of an air-infeed arrangement for controlling or regulating the infeed of air to the driving-gas chamber 4. Fig. 2 only illustrates the part of a lung ventilator which is of most interest in this connection, namely the rigid container 1 divided into the breathing-gas chamber 3 and the driving-gas chamber 4 by means of the diaphragm 2. The breathing-gas chamber 3 is connected to the supply line 5 and the inspiration line 9 in the previously described manner. The air-infeed arrangement for feeding air into the driving-gas chamber 4 so as to increase its volume and/or so as to generate a desired pressure therein, includes, in this embodiment of the invention, a fan 16 which is intended to be operated continuously and which is arranged to blow air from the surrounding atmosphere into the driving-gas chamber 4, said chamber being provided with an outlet 17 which communicates with the surrounding atmosphere and which incorporates a variable throttle arrangement 18 which is controlled by means of an electric control signal from the control unit 8. The variable, controllable throttle arrangement 18 is so arranged that when fully open it presents a through-flow area of such magnitude that no overpressure occurs in the driving-gas chamber 4 vis the surrounding atmosphere. The more the throttle arrangement 18 is closed under the action of an applied electric signal, the higher the dammed pressure generated within the driving-gas chamber 4 under the influence of the flow of air caused by the fan 16, into the chamber 4. This arrangement affords over the arangement illustrated in Fig. 1 the advantage whereby no compressed-air network or no other form of compressed-air source is required, which is an important advantage in many cases.

The lung ventilator illustrated in Fig. 1 also includes a pressure comparator 19 of suitable design, which is connected to the driving-gas chamber 4 and the breathing-gas chamber 3 and arranged to compare the pressure prevailing in said two chambers and to send a signal to the control unit 8 when the pressure in the chamber 4 tends to increase above the pressure in the chamber 3. Such an increase in pressure occurs when the breathing-gas chamber 3 is completely empty and the ejector 13 continues to feed air into the driving-gas chamber 4.

The lung ventilator also incorporates a pressure transducer 20 which is connected to the inspiration line 9 and which senses the pressure prevailing in said line, and therewith also in the hose 10 and the airways of the patient, and sends a corresponding measuring signal to the control unit 8.

Finally, the illustrated lung bentilator includes an expiration line 21 which is connected to the hose 10 and which incorporates an expiration valve 22 in the form of a pressure-control check valve, said valve permitting gas to flow only in a direction away from the patient and which is only opened when the pressure in the expiration line 21 and the hose 10, and therewith also in the airways of the patient, exceeds an applied control pressure which is obtained through a control-pressure line 23 from the brea-

thing chamber 3. The control pressure of the expiration valve 22 thus coincides with the pressure prevailing at that moment in the breathing-gas chamber 3. It is an advantage if the control-line 23 incorporates a closure valve 24 which is operated from the control unit 8. Normally, the gas exhaled from the expiration valve 22 passes to a means (not shown) for measuring the volume of gas exhaled.

If the lung ventilator illustrated in Fig. 1 is to be used for a continuous mandatory or mechanical ventilating treatment process (CMV), the valve 7 in the supply line 5 to the breathing-gas chamber 3 is constantly held open, or is omitted. Further, the flow meter 12 in the inspiration line 9 can also be omitted, as can also, in the simplest form of the ventilation, the pressure transducer 20 and the closure valve 24 in the control-pressure line 23 of the expiration valve 22. The source 6 of breathing gas is set so as to provide a flow corresponding to the average volume of breathing gas to be supplied to the patient per unit of time. This flow of breathing gas flows constantly into the breathing-gas chamber 3. The control unit 8 is designed and adapted to control the regulating valve 15 periodically at a desired frequency coinciding with the desired breathing frequency. During each inspiration phase the control unit 8 sends to the regulating valve 15 a control signal of pre-determined shape, causing the ejector 13 to feed air into the driving-gas chamber 4, the volume of which is thereby increased so as to cause the breathing-gas chamber 3 to be compressed and the quantity of breathing gas collected therein during the expiration phase of the preceding breathing cycle to be forced out through the line 9 and the hose 10, to the airways of the patient. This continues until the breathing-gas chamber 3 is completely empty, this state of the chamber being sensed by the pressure comparitor 19 in the manner previously mentioned and reported through a corresponding signal to the control unit 8, which, in the simplest embodiment of the ventilator, therewith interrupts the control signal to the regulating valve 15 so as to close said valve. This causes the ejector 13 to stop, so that the pressure in the driving-gas chamber 4 is rapidly reduced to atmospheric pressure. In this way, the pressure in the breathing-gas chamber 3 will also equal atmospheric pressure and the breathing-gas from the source 6 will again begin to fill the chamber 3. Hereby, the inspiration phase is also interrupted, and the patient is able to exhale through the expiration line 21 and the expiration valve 22, the closing pressure of which is reduced to atmospheric pressure as a result of the decrease in pressure in the chamber 3.

The pressure-flow-profile for the supply of breathing gas to the airways of the patient during the inspiration phase can be determined by means of the shape and magnitude of the control signal generated by the control unit 8 and sent thereby to the regulating valve 15 during the inspiration phase. If this control signal is such as to provide a relatively low flow from the ejector 13 to the chamber 4, and therewith a low stagnation pressure therein, the flow of breathing gas from the chamber 3 of the airways of the patient will fall as the pressure in said airways rises. If, on the other hand, the regulating valve 15 receives a control signal which provides a high flow across the ejector 13, and therewith a high stagnation pressure in the chamber 4, the fall in flow of breathing gas from the chamber 3 to the airways of the patient will be considerably less, or only very slight, as the pressure in the airways rises. The regulating valve 15 can also be supplied with a control signal which increases linearly and which provides a continuously increasing flow from the ejector to the chamber 4. In this case, the breathing gas flows from the chamber 3 to the airways of the patient under a linearly increasing pressure in the said airways. The rate in which the increase in pressure takes place, i.e. the inclination of the pressure ramp, is dependent on the resistance and resilience of the patient's lungs. These different pressure-flow-profiles for the supply of breathing gas to the airways of the patient during each inspiration phase can thus be obtained without the provision of a closed control loop, solely by generating a suitable control signal having a desired shape and applying said signal to the regulating valve 15. If it is desired to obtain an accurately pre-determined pressure curve in the airways of the patient during the inspiration phase, irrespective of the state of the patient's lungs, this can be achieved by providing the lung ventilator with the pressure transducer 20, which detects the pressure prevailing in the airways of the patient and sends to the control unit 8 a measuring signal corresponding to the sensed pressure. The control unit 8 in this case is arranged to generate during each inspiration phase a reference signal representative of the desired pressure curve in the airways of the patient, this reference signal being compared, in a conventional manner, with the measuring signal received from the pressure transducer 20, and a control signal is generated and sent to the regulating valve 15, causing the difference between the two compared signals to be held substantially at zero.

As previously mentioned, it is often desired to carry out a respiratory treatment process with a given, positive end expiration pressure, so-called PEEP. This can readily be achieved in a lung ventilator according to the invention by so constructing the guide unit 8 that there is also sent to the regulating valve 15, during the expiration phase of each breathing cycle, a given control signal which gives rise to a pre-determined pressure in the driving-gas chamber 4 corresponding to the desired PEEP-value. Thus, as previously mentioned, the pressure in the chamber 3 will coincide with the pressure in the chamber 4, and hence there is supplied to the expiration valve 22, during the expiration phase, a controlling pressure or closing pressure corresponding to said desired PEEP-value. The patient will thus exhale at the desired end pressure, the value of which can be changed by changing the control signal sent by the control unit 8 to the regulating valve 15.

Since the breathing-gas chamber 3 is completely emptied during each inspiration phase, the patient will be supplied at each mandatory breath with a pre-determined constant volume of breathing gas corresponding to the volume of breathing gas delivered by the source 6 to the chamber 3 during the period of a full breathing cycle.

Subsequent to supplying the airways of the patient with the desired volume of breathing gas during an increase in pressure in said airways, it is often desirable for the amount of gas supplied to be momentarily distributed to all parts of the lungs of the patient, so that all of the alveoli have time to be filled with breathing gas before commencement of the expiration phase. Such a pressure-equalizing plateau between the inspiration and expiration phase can be achieved in a lung ventilator according to the invention by providing the control-pressure line 23 of the expiration valve 22 with a closure valve 24, which is normally held completely open but which, under the action of the control unit 8, is closed at the same time as inspiration is interrupted, by interrupting the control signal to the regulating valve 15, or by reducing said signal to a value corresponding to the desired PEEP-value, and then holding said valve closed over a period corresponding to the desired pressure-equalizing plateau. While the valve 24 is held closed in this manner, the pressure prevailing at the end of the inspiration phase in the line 23 between the valve 24 and the expiration valve 22 is maintained, which valve 22 is thus still held closed and prevents air from being exhaled from the airways of the patient, so that the volume of breathing gas supplied can be distributed in said airways. subsequent to the termination of the desired plateau interval, the valve 24 is again opened by the control unit 8 so that the control pressure to the expiration valve 22 is lowered to the pressure now prevailing in the breathing chamber 3 (atmospheric pressure or the desired PEEP-pressure) whereafter the patient is able to exhale in the normal manner.

In other kinds of respiratory treatment processes, for example with the spontaneous breathing of patients, with IMV and IDV processes, the volume of breathing gas obtained by the patient during each breath is not previously known, but will vary, for example, in dependence on the ability of the patient to breath himself, and will also vary from breath to breath. In this case, the breathing-gas chamber 3 will not be completely emptied at each breath, and hence in this case the lung ventilator is provided with the flow-meter 12, which continuously measures the flow of breathing gas passing through the line 9 and supplied to the airways of the patient, and sends a corresponding measuring signal to the control unit 8, which comprises suitable means for integrating said flow signal over desired time periods, for establishing the volume of breathing gas supplied to the patient. In such respiratory treatment processes, the source 6 of breathing gas is set to a flow-rate which is so high that it will positively correspond to the maximum demand. In order to save breathing gas, the closure valve 7 in the feed line 5 to the chamber 3 is so controlled by the control unit 8 in response to the flow signal from the flow meter 12 that there is always a minimum requisite quantity of breathing gas in the chamber 3. The breathing-gas chamber 3 might in this case be filled to its maximum volume from the source of breathing gas, and even overfilled. To prevent this from resulting in an uncontrollable rise in pressure in the chamber 3, the membrane 2 of the illustrated embodiment of the invention is provided with a leakage valve 25 which opens automatically when the breathing-gas chamber 3 reaches its maximum volume and the diaphragm 2 is thereby pressed against the upper wall of the container 1. When the valve 25 opens, breathing gas is permitted to leak from the chamber 3 to the chamber 4.

In spontaneous breathing processes it is possible by means of the lung ventilator to obtain a desired, continuous positive overpressure in the airways of the patient, so-called CPAP, by arranging for the control unit 8 to generate, during the spontaneous breathing process, a reference signal corresponding to the desired CPAP, said signal being compared with the pressure signal from the pressure transducer 20, the control signal to the regulating valve 15 being so adapted that the difference between the two compared signals is maintained substantially at zero. Spontaneous breathing of the patient will then take place relative to the CPAP determined by the control unit 8.

For the purpose of further improving the spontaneous breathing of the patient and for achieving a very small deviation from the desired CPAP-level and, at the same time, an insignificant tendency to self oscillation of the regulating system, the signal from the flow meter 12, in addition to the pressure signal from the pressure transducer 20, can also be fed back for comparison with the reference signal corresponding to the desired CPAP-value. The signal from the pressure transducer 20 and the signal from the flow meter 12 are amplified to different levels in the feedback before they are summated and the summation signal is compared with the reference signal.

When applying an intermittent, mandatory ventilation process, so-called IMV, the mandatory breaths are initiated with an adjustable frequency determined by the control unit 8, by the fact that the control unit 8 generates a corresponding control signal in one of the modes described hereinbefore, and sends said signal to the regulating valve 15, i.e. either quite simply by applying a control signal of desired shape to the regulating valve 15, or by generating a reference signal corresponding to the desired pressure curve in the airways of the patient during said breath, and comparing said reference signal with the measuring signal received from the pressure transducer 20, whereat the control signal to the regulating valve 15 is adapted to hold the difference between the compared signals substantially at zero. The duration of the mandatory breath is determined herewith by means of the flow signal from the flow meter 12, which signal is integrated in the control unit 8 during the breath which is interrupted by the action of the control signal to the regulating valve 15, when the volume of breathing gas supplied to the patient during said breath coincides with a pre-determined, desired tidal volume set in the control unit 8. It will be understood that a pressure-equilization plateau can also be obtained in the previously described manner after such a mandatory breath, by temporarily closing the valve 24.

When subjecting a patient to an IDV-process, each

mandatory breath is triggered by the attempt of the patient to inhale, owing to the fact that the control unit 8 senses the flow signal from the flow meter 12 and detects the increase in flow occurring when the patient begins to draw in breathing-gas from the chamber 3 through the inspiration line 9, whereat the control unit 8 is arranged to initiate a breath in any of the ways hereinbefore described, in response to this increase in flow.

It will be understood that the arrangement illustrated in Fig. 2 can operate in a manner corresponding to that illustrated in Fig. 1 and hereinbefore described, whereat the variable throttle arrangement 18 of the Fig. 2 embodiment is controlled from the control unit 8 in a manner corresponding to the manner in which the regulating valve 15 of the Fig. 1 embodiment is controlled. It should be noted in this respect that the result of closing the variable throttle arrangement 18 in Fig. 2 corresponds to that obtained when opening the regulating valve in Fig. 1.

CLAIMS

1. A lung ventilator comprising an inspiration line which incorporates a check valve which permits gas to flow only in a direction towards a patient, an expiration line which incorporates an expiration valve which is operable only during the expiration phase of a breathing cycle of the patient, a variable volume breathing-gas chamber which is connected through a supply line to a breathing gas source and through the inspiration line to the airways of the patient, a driving-gas chamber which is connected to an air supply arrangement so that upon supply of air to the driving gas chamber the breathing gas chamber is compressed to drive breathing gas into the patient, the air supply arrangement comprising an electrically controllable regulating means arranged to vary the effective air infeed and therewith the pressure generated in the driving gas chamber in dependence on an applied control signal, and a control unit which generates a control signal having a predetermined shape during each breath and sends this signal to the regulating means.

2. A lung ventilator according to claim 1 in which the breathing gas chamber comprises at least partially flexible walls.

3. A lung ventilator according to claim 1 or claim 2 in which the driving gas chamber comprises rigid walls.

4. A lung ventilator according to claim 1 in which the breathing gas chamber is separated from the driving gas chamber by a flexible membrane.

5. A lung ventilator according to any one of claims 1 to 4, in which the air supply arrangement includes an ejector which is coupled between the driving-gas chamber and the surrounding atmosphere and has a driving nozzle connected to a compressed-air source through an electrically controllable flow regulating valve forming said regulating means.

6. A lung ventilator according to anyone of claims 1 to 4, in which the air supply arrangement includes a fan arranged between the surrounding atmosphere and the driving-gas chamber, and an outlet from the driving-gas chamber to said surrounding atmosphere, said outlet including an electrically controllable, variable throttle-arrangement which forms said regulating means.

7. A lung ventilator according to claim 5, including means for connecting the driving-gas chamber to the surrounding atmosphere through a pressure-loaded valve which is held closed by a pressure derived from the feed pressure to the drive nozzle of the ejector.

8. A lung ventilator according to any one of claims 1 to 7, in which the expiration valve has the form of a pressure-loaded check valve which is held closed by a control pressure derived from the pressure in the breathing-gas chamber, and the control unit is arranged, during the expiration phase of each mandatory breath and during spontaneous breathing of the patient, to generate a constant control signal having a predetermined magnitude corresponding to a predetermined, substantially constant pressure in the driving-gas chamber, which is lower than the pressure generated in the driving-gas chamber during the inspiration phase of a mandatory breath, and to send said signal to said regulating means.

9. A lung ventilator according to any one of claims 1 to 8, which comprise means for sensing and comparing the pressures in the driving-gas chamber and the breathing-gas chamber and for sending to the control unit a signal dependent on said comparison, said unit being arranged, in response to said signal, to interrupt a proceeding inspiration phase for a mandatory breath by changing the control signal to the regulating means when the pressure in the driving-gas chamber tends to exceed the pressure in the breathing-gas chamber.

10. A lung ventilator according to any one of claims 1 to 8, which comprises means for measuring the flow of breathing gas through the inspiration line and for generating a corresponding flow signal to the control unit, which is arranged, in response to said flow signal, to interrupt a proceeding inspiration phase for a mandatory breath by changing the control signal to the regulating means when the volume of breathing gas passing through the inspiration line during the inspiration phase in question has reached a predetermined value.

11. A lung ventilator according to any one of claims 1 to 10, which comprises a pressure transducer connected to the inspiration line for sensing the pressure prevailing in the airways of the patient and for generating a corresponding pressure signal and sending said signal to the control unit which is arranged to generate a reference signal representative of the desired pressure in said airways at that time and to compare said reference signal with said pressure signal and constantly hold the control signal to the regulating means at a level such that the difference between the two compared signals is held substantially at zero.

12. A lung ventilator according to any one of claims 1 to 10, which comprises a pressure transducer connected to the inspiration line for sensing the pressure prevailing in the airways of the patient and for generating a corresponding pressure signal to the control unit; and means for measuring the

flow of breathing gas through the inspiration line and for generating a corresponding flow signal to the control unit said control unit being arranged to generate, during spontaneous breathing of the patient, a reference signal representative of the desired pressure level in the airways of the patient and to compare this reference signal with a weighted sum of said pressure and flow signals, and in response to this comparison to hold the control signal to the regulating means at a value such that the difference in said comparison is displaced towards zero.

13. A lung ventilator according to claim 10, in which the control unit is arranged, in response to the flow signal, to trigger the inspiration phase for a mandatory breath by a corresponding change in the control signal to the regulating means when a temporary increase in the flow of gas in the inspiration line indicates an attempt by the patient to inhale.

14. A lung ventilator according to claim 10, in which the supply line to the feeding-gas chamber incorporates a closure valve operable by means of the control unit, and the control unit is arranged, in response to said flow signal, to hold said valve open or closed respectively over such intervals of time that the breathing-gas chamber always contains a predetermined minimum volume of breathing gas.

15. A lung ventilator according to any one of claims 1 to 14, in which a flexible wall of the breathing-gas chamber is provided with a normally closed valve which is arranged to be automatically opened to permit leakage of breathing gas from the breathing-gas chamber when said flexible wall takes the position corresponding to the maximum volume of said breathing-gas chamber, thereby preventing overfilling of said chamber.

16. A lung ventilator according to any one of claims 1 to 15, in which the expiration valve has the form of a pressure-loaded check valve which is held closed by a control pressure applied through a control-pressure line connected to said breathing-gas chamber, which line has incorporated therein a normally open closure valve controlled by the control unit which is arranged, at the termination of a mandatory breath, to close said valve at the same time as the control signal to said regulating means is changed for reducing the pressure in the driving-gas chamber and therewith the breathing-gas chamber, and to hold the valve closed over a predetermined period of time during which the volume of breathing gas supplied at that time to the airways of the patient is able to distribute itself to said airways before the expiration phase commences, by the fact that the valve is again opened so that the control pressure of the expiratory valve drops and the expiration valve can be opened by the overpressure prevailing in the airways of the patient.

17. A lung ventilator comprising a variable volume breathing gas chamber which, in use, responds to the pressure in a driving gas-chamber to supply air to a patient, a control unit which generates a control signal having a predetermined shape during each breath, and an electrically controllable regulating means which is responsive to the control signal to vary the pressure in the driving-gas chamber.

18. A lung ventilator substantially as hereinbefore described with reference to and as illustrated in Figure 1 of the accompanying drawings.

19. A lung ventilator substantially as hereinbefore described with reference to and as illustrated in Figure 2 of the accompanying drawings.

20. Any novel feature or combination of features as disclosed herein.

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Fig. 1

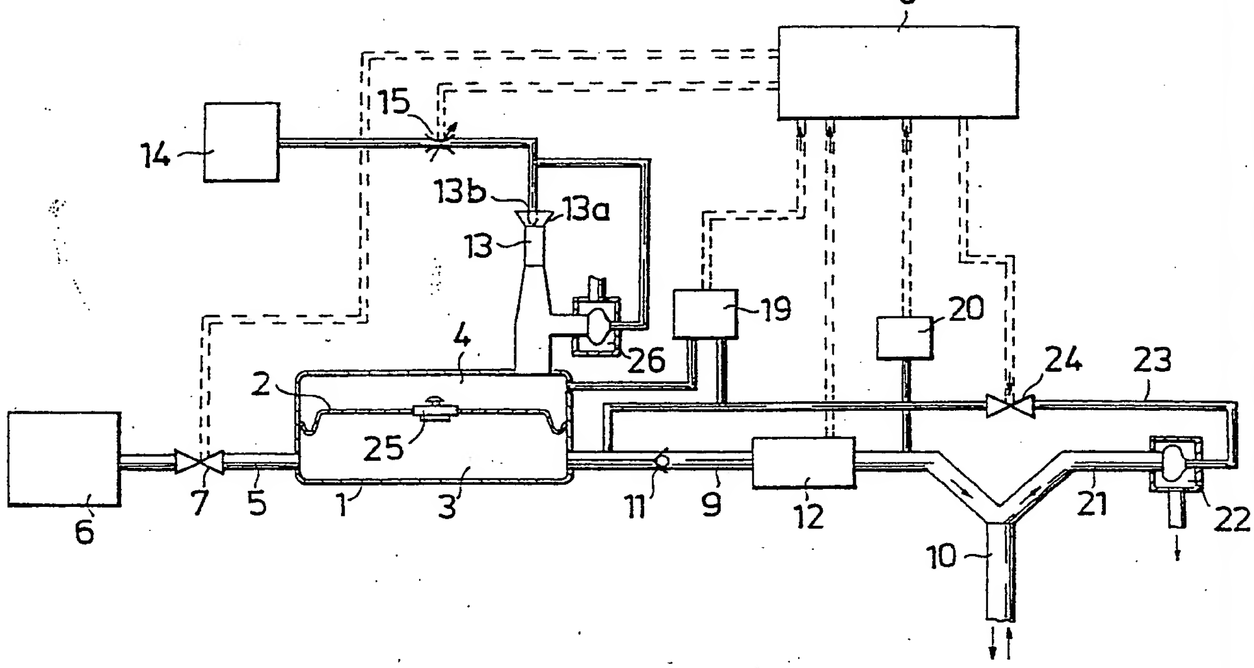
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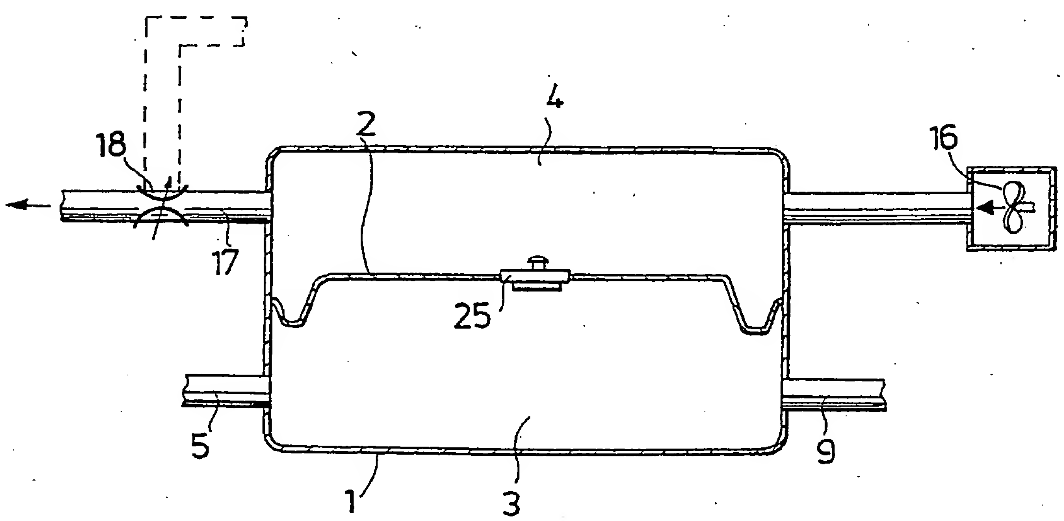
Fig. 2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